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Contributed Paper

Estimation of Anisotropy Parameters, δ and ε: An Application to Borehole and Seismic Data from Ketzin, Germany

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ABSTRACT

Weak anisotropy was indicated in a previous investigation of the 3D baseline seismic data acquired through the EU funded CO_2SINK project at the Ketzin pilot site for CO_2 storage, Germany. Fourth order velocity analysis yielded the Alkhalifah anellipticity factor, or eta (η), ranging from -0.2399 to 0.1341 for the whole study area. Although application of the simple η term in the moveout correction allowed reflections to be flattened at far offsets, resulting in an improved seismic stacked section, the Thomsen parameters, delta (δ) and epsilon (ε) are of greater interest from a rock physics perspective. Borehole data from Ketzin were introduced to estimate δ and ε using known relationships between sonic wave velocity, NMO velocity, η, δ and ε. In this paper, δ and ε estimations were performed using data from three wells; the CO_2 injection well and two observation wells. Preliminary estimates of the Thomsen parameters give δ ranging from -0.2658 to -0.1270, while ε ranges from -0.2611 to -0.1141. These δ and ε values also indicate the presence of weak vertical transverse isotropy at the site, which is consistent with the previous study.

Keywords: seismic anisotropy, borehole, reflection, Ketzin

1. INTRODUCTION

Although anisotropic seismic processing technique, used to flatten far offset reflections, has turned into a standard procedure in commercial processing projects, the process is not sufficient to resolve all transverse isotropy parameters [1]. Knowledge of the anisotropy parameters provides better understanding of the rock physics of the subsurface formations and, subsequently, contributes to a variety of applications of these parameters. In terms of seismic data processing, introducing anisotropy parameters in the velocity model results in a better focusing and positioning of the seismic reflections [2]. For example, Alkhalifah and Tsvankin (1995) [3], Alkhalifah (1997) [4] and Tsvankin (2012) [5] successfully applied nonhyperbolic moveout to long-spread reflection seismic data. Estimation of the anisotropic parameters can be performed by several methods, either by a direct measurement of velocity on core samples [6, 7] or from seismic and/or borehole data [1, 8] followed by a subsequent inversion of the velocity into the stiffness tensors and anisotropy parameters.

At the Ketzin pilot site for CO_2 storage in Germany the sedimentary strata with anticlinal and faulting structures [9, 10] have been found to contain weak anisotropy [11]. A material is considered to be weakly anisotropic when its anisotropy parameters are much less than 1 [6]. Anisotropy can produce non-flat reflections at the far offset range after normal moveout (NMO) and this could lead to distortion in the final section if stacking all the offset data without taking anisotropy into account. A previous study on anisotropy at Ketzin was performed on 3D seismic data assuming vertical transverse isotropy. The Alkhalifah anellipticity factor or eta (η) could be determined only by fourth order velocity analysis. Including η into the seismic data processing improves the final seismic section of the CO_2 pilot storage site at Ketzin [11]. However, using seismic data alone cannot solve for other anisotropic parameters even though η is the product of Thomsen's epsilon and delta (ε and δ) parameters. Therefore, borehole data from Ketzin were introduced to estimate δ and ε. The parameter ε describes the ratio between horizontal and vertical velocities or rock compressibility and δ describes the ratio between normal moveout velocities and vertical velocities [12, 13].

In this study, we performed an estimation of δ and ε by using the velocities from seismic and borehole data. Seismic data provide information on NMO velocity (V_{nmo}) and η, whereas sonic logs from borehole data provide information on vertical velocity (V_{vo}). Estimated δ and ε can be used for further study in terms of the external seismic attributes for lithologic interpretation.

2. MATERIALS AND METHODS

2.1 Data Set

Seismic data used in this study are the 3D baseline seismic data acquired in 2005 at Ketzin [9]. The data acquisition used a template system with the same nominal acquisition parameters for each template. Acquisition parameters are given in Table 1. The survey comprised 41 templates within 9 swaths. Location of the Ketzin site is illustrated in Figure 1. Seismic processing of the baseline data based on a fourth order velocity analysis provides V_{nmo} and η velocity functions which are used in the δ and ε evaluations. These two velocity functions were exported at the well locations where anisotropy is expected to be present (Figure 2).

Table 1. Acquisition parameters [9].

Parameter	Value
Receiver line spacing/number	96 m / 5
Receiver station spacing/ channels	24 m / 48
Source line spacing/number	48 m / 12
Source point spacing	24 m or 72 m
CDP bin size	12 m x 12 m
Nominal fold	25
Geophone	28 Hz single
Sampling rate	1 ms
Record length	3 s
Source	240 kg accelerated weight drop, 8 hits per source point
Acquisition unit	Sercel 408 UL

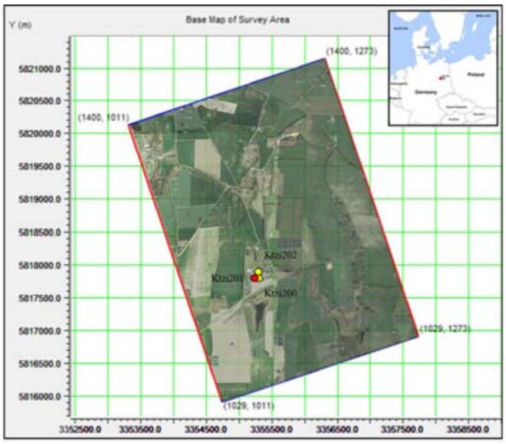

Figure 1. Location of the Ketzin pilot CO_2 storage site, Germany. The survey covers 372 inlines (blue line) and 263 crosslines (red line) with 3 wells; the CO_2 injection well (Ktzi201) is marked with the red dot and two observation wells (Ktzi200 and Ktzi202) with the yellow dots.

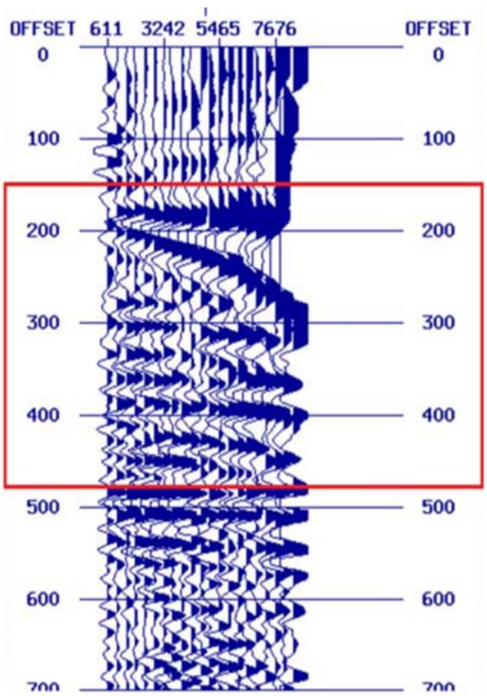

Figure 2. Effect of anisotropy after NMO correction without stretch mute applied [11].

Borehole data consist of sonic and density logs from 3 wells; the CO_2 injection well (Ktzi 201) and two observation wells (Ktzi 200 and Ktzi 202), which were drilled in 2007 to a depth of approximately 800 meters [14]. The distances from the injection well to the two observation wells are 50 meters to the east (Ktzi200) and 110 meters to the northeast (Ktzi 202) [15]. Locations of the three wells are also illustrated in Figure 1.

2.2 Anisotropy Parameter Estimation

In order to estimate δ and ε, the following steps have been applied.

- **V_{nmo} and η measurements**

In order to extend the seismic processing to a vertical transverse isotropic medium, velocity analysis was carried out in two steps. First, NMO velocity picking was done in the near to middle offset range. Since the 3D baseline data from Ketzin has a limited offset range, the whole data set was used to perform the NMO velocity analysis. Consequently, the normal moveout correction was applied to the entire data set without applying a stretch mute. An anisotropic effect appears only in the shallow part due to the limited availability of the far offsets (Figure 2). Therefore, the study of anisotropy in this area was performed only in the interval in which anisotropy can be detected if present. In the second step, η values were picked in order to flatten the far offset reflections. Both V_{nmo} and η were picked by using semblance velocity analysis. By the two-step velocity picking, V_{nmo} and η models were obtained (Figure 3).

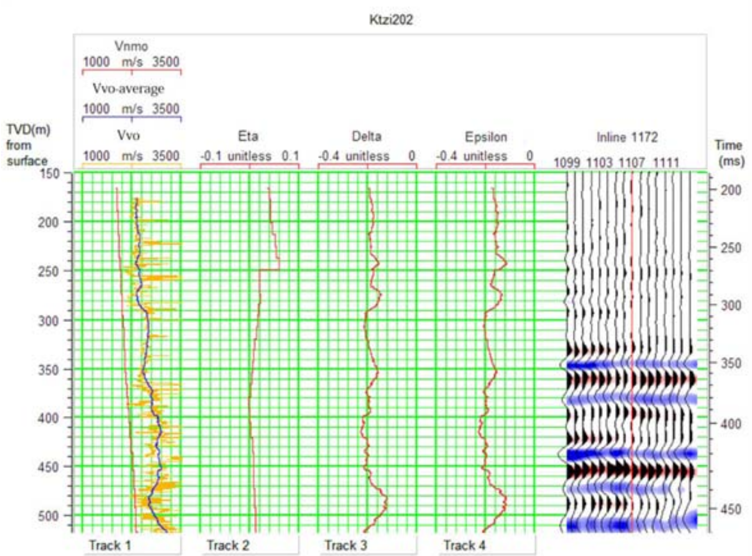

Figure 3. Example of δ and ε evaluation. Track 1 and 2 are input data for calculation. V_{nmo} (Track 1) and Eta (Track 2) are obtained from seismic data. V_{vo} is a sonic velocity. V_{vo}*-average* is averaged from V_{vo}. Delta (Track 3) and Epsilon (Track 4) are calculated δ and ε. The last Track is the seismic data at Inline 1172, where well Ktzi202 cuts through (red line).

• **V_{vo} averaging**

Since the boreholes at the Ketzin site are vertical and a broad and gentle anticline is present, we assume that the wells are relatively orthogonal to the bedding. Therefore, we assume the sonic velocity represents V_{vo}. However, velocities from the borehole data and the seismic data are of different resolution scales. Therefore, the velocity from the sonic log needs to be averaged following the anisotropy theory of Backus [8, 16]. Original and averaged V_{vo} curves are displayed in Figure 3.

• **δ and ε estimation**

The well-known Thomsen (1986) [6] and Alkhalifah and Tsvankin (1995) formulas [3] were used to estimate δ and ε. These two formulas are the following:

$$\delta = \frac{1}{2}\left(\left[\frac{V_{nmo}}{V_{vo}}\right]^2 - 1\right) \quad (1)$$

$$\varepsilon = \eta + \delta\,(2\eta + 1) \quad (2)$$

where δ and ε were estimated for each individual well.

3. Results and Discussions

Preliminary results of the inverted δ and ε vales are summarized in Table 2. Presented are the minimum, maximum and average degree of anisotropy along with the standard deviation (SD) of the whole data set for each well. The degree of anisotropy is represented by its sign, which could be positive or negative, and its magnitude. A graphic representation of the δ and ε evaluations at the Ktzi202 well is displayed in Figure 3. Figure 4 shows the results of the δ and ε calculations for each well. Overall, δ and ε show small negative values. Normally, δ and ε are assumed to be positive [12, 13]. However, some negative values have been measured [6].

Table 2. Inverted δ and ε classified by wells.

Well	Degree of anisotropy	δ	ε
Ktzi200	Minimum	-0.1291	-0.1224
	Maximum	-0.2658	-0.2611
	Average	-0.2014	-0.1921
	SD	0.0277	0.0334
Ktzi201	Minimum	-0.1270	-0.1214
	Maximum	-0.2598	-0.2604
	Average	-0.2032	-0.1944
	SD	0.0287	0.0342
Ktzi202	Minimum	-0.1238	-0.1141
	Maximum	-0.2495	-0.2441
	Average	-0.1907	-0.1807
	SD	0.0260	0.0307

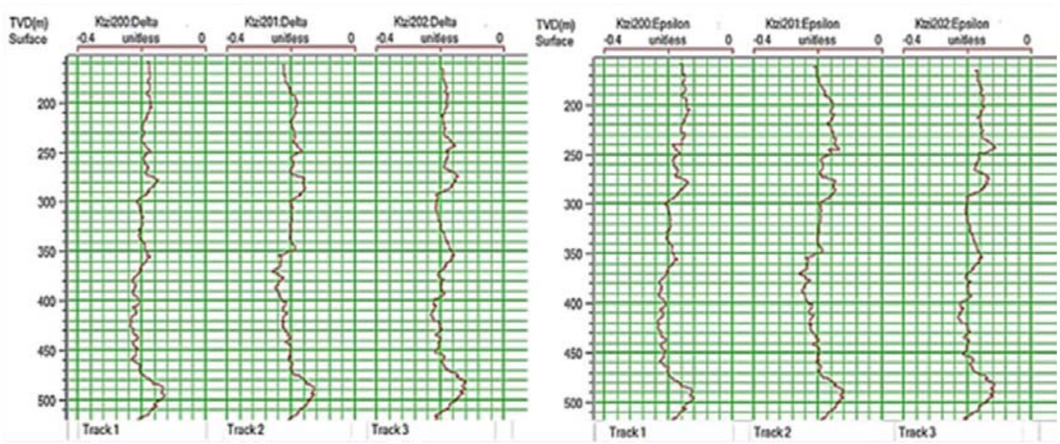

Figure 4. The plot of estimated δ (a) and ε (b) for each individual well.

The minus sign of δ indicates that the vertical velocity is greater than the normal moveout velocity based on the second order velocity analysis as shown in Track 1 of Figure 3. Typically, sonic velocities are faster than seismic velocities [17]. This is because elastic wave velocities almost always increase with frequency and, therefore, sonic velocities tend to be higher than seismic velocities. In an attempt to get a seismic-band vertical velocity from the sonic velocities, all borehole data were up-scaled by the averaging method. V_{nmo} and V_{vo} are assumed to represent the same frequency content after upscaling. This would allow the difference between V_{nmo} and V_{vo} to be attributed to the presence of anisotropy. The small values of δ indicate that the degree of anisotropy is weak. However, the upscaling may not have completely accounted for the differences in propagation velocity due to frequency.

As for the minus sign of ε, it indicates that the vertical velocity is greater than the horizontal velocity. Note that the vertical velocity in this study is the seismic-band frequency velocity or seismic P-wave velocity at normal incidence. The higher velocity in the vertical direction than in the horizontal direction can be explained by the rock being less compressible in the vertical direction compared to the horizontal direction. The small values of ε indicate weak anisotropy as well. However, differences in the scales of measurement in the vertical and horizontal directions may also play a role in the estimates of δ and ε. From this study, δ and ε were estimated at the well locations. To resolve the subsurface image, they must be consistently extrapolated to the entire seismic volume using the interpreted horizons.

4. Conclusions

The study on the presence of transverse isotropy at the Ketzin CO_2 injection site has been extended to include logging data. Combining velocity information from seismic and well data can provide the Thomsen parameters, δ and ε. The estimation yields δ ranging from -0.2658 to -0.1270 and ε ranging from -0.2611 to -0.1141. These δ and ε indicate weak vertical transverse isotropy which is consistent with the previous study of η obtained from seismic data only.

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References

[1] Bachrach R., Osypov K., Nichols D., Yang Y., Liu Y. and Woodward M., *Geophysical Prospecting*, 2013; **61**: 404-415. DOI 10.1111/j.1365-2478.2012.01133.x.

[2] Tsvankin I., Gaiser J., Grechka V., Bann M. and Thomsen L., *Geophysics*, 2010; **75**: 75A15-75A29. DOI 10.1190/1.3481775.

[3] Alkhalifah T. and Tsvankin I., *Geophysics*, 1995; **60**: 1550-1566. DOI 10.1190/1.1443888.

[4] Alkhalifah T., *Geophysics*, 1997; **62**: 662-675. DOI 10.1190/1.1444175.

[5] Tsvankin I., *Seismic Signatures and Analysis of Reflection Data in Anisotropic Media,* 3rd Edn., Society of Exploration Geophysicists, 2012.

[6] Thomsen L., *Geophysics*, 1986; **51**: 1954-1966. DOI 10.1190/1.1442051.

[7] Ahmadi P. and Malehmir A., *ASEG Extended Abstracts of 24th International Geophysical Conference and Exhibition (ASEG-PESA 2015)*, Perth, Australia, 15-18 February 2015; 1-4.

[8] Liner C.L. and Fei T.W., *Geophysics*, 2006; **71**: D183-D190. DOI 10.1190/1.2356997.

[9] Juhlin C., Giese R., Zinck-Jørgensen K., Cosma C., Kazemein, H., Juhojuntti N., and Förster A., *Geophysics*, 2007; **72**: B121-B132. DOI 10.1190/1.2754667.

[10] Förster A., Giese R., Juhlin C. and Norden B., *Energy Procedia*, 2009; **1**:

2911-2918. DOI 10.1016/j.egypro.2009.02.066.

[11] Kruachanta M., Ivandic M. and Juhlin C., *Energy Procedia*, 2015; **76**: 549-554. DOI 10.1016/j.egypro.2015.07.908.

[12] Thomsen L., *Understanding Seismic Anisotropy in Exploration and Exploitation*, SEG/EAGE DISC, USA, 2002.

[13] Robein E., EAGE E-Lecture: On the use of Epsilon and Delta in Anisotropic Velocity Model Building and Depth Migration; Avalaible at: https://www.linkedin.com/company/eage-european-association-of-geoscientists-and-engineers-.

[14] Prevedel B., Wohlgemuth L., Legarth B., Henninges J., Schütt H., Schmidt-Hattenberger C., Norden B., Förster A. and Hurter S., *Energy Procedia*, 2009; **1**: 2087-2094. DOI 10.1016/j.egypro.2009.01.272.

[15] Huang F., Juhlin C., Kempka T., Norden B. and Zhang F., *Int. J. Greenhouse Gas Control*, 2015; **36**: 66-77. DOI 10.1016/j.ijggc.2015.02.020.

[16] Backus G.E., *J. Geophys. Res.*, 1962; **67**: 4427-4440. DOI 10.1029/JZ067i011p04427.

[17] Schlumberger, *Log Interpretation Principles/Applications*, 2nd Edn., Schlumberger Educational Services, Houston, 1989.